THE RELATION OF FATIGUE TO INDUSTRIAL ACCIDENTS

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I. INTRODUCTION[1]

The discussion of any question relative to industrial accidents remains incomplete if the influences and possible consequences of fatigue are not considered.[2] The origin of the problem of fatigue in industry is to be found in connection with the industrial revolution. Before the introduction of the factory system, employer and employee usually worked side by side as companions. The blacksmith had a helper or two; the farmer had his "hired hand"; the shoemaker, an apprentice. Tools were simple; accidents, rare. The occupations were usually not hazardous; the existing dangers, if any, were obvious. People generally worked from "sun to sun," but in a more or less leisurely fashion.

When hand-driven tools were supplanted by power-driven machinery, and the home gave way to the factory as the unit of production, the long hours of labor were carried over. Monotonous, speeded-up processes took the place of interesting forms of work at a leisurely rate. At about the same time, work by artificial light was made possible. Consequently, work-hours, instead of being shortened to suit the new mechanical processes, were "considerably lengthened, and in the case of child labor particularly, to a cruel degree."[3] As late as 1842, for instance, the working day in cotton mills (United States) was fourteen hours long. When domestic industry was supplanted by the factory system, not only men but women and children in large numbers were subjected to the monotonous, speeded-up processes of machine labor and for extremely long hours. Herein is to be found the origin of the problem of fatigue in industry.

[1] I am indebted to Professor C. R. Henderson for suggesting this problem.

[2] A. Imbert, *14 Intern. Kongr. f. Hyg. u. Demog.*, II, 634.

[3] Adams and Sumner, *Labor Problems* (Macmillan, 1908), 515.

From such a beginning, the fatigue problem developed rapidly under cover of the *laissez-faire* philosophy of the last century. It was held by the theorists that if labor conditions became too severe in one factory, the laborers would leave and flock to other factories where more favorable conditions existed. But such freedom of choice was not actually open to working men and women, for the severe labor conditions came to prevail generally. In this way, under the protection of *laissez faire,* the fatigue problem came to assume amazing proportions. Thus it has escaped social vigilance until within the last few years, and today it presents almost insuperable difficulties. It has recently been said that among the many problems of industrial hygiene, the most important has hitherto been most neglected—the problem of industrial overstrain. Josephine Goldmark designates overfatigue as "the commonest and most subtle danger of occupation," and says that in the United States this danger

> has not yet been faced nor even fairly stated; yet no one element of industry is more fraught with peril for workers. Indeed, overfatigue or exhaustion —*surmenage* as the French call it—affects every department of life, physical and economic, mental, moral. It predisposes to disease; it destroys intelligence and all the habitual restraints; it cuts down output and impairs its quality; it invites industrial accidents. It affects not only workers in admittedly dangerous occupations but all workers—every man, woman, and child employed for excessive working hours.[4]

The problem of fatigue in industry has at least six phases: (*a*) the relation of fatigue to industrial accidents; (*b*) fatigue and industrial inefficiency—presumably poorer work and less work is done in the last hour of a day's labor than in other hours; (*c*) fatigue and contagious diseases—an overworked laboring man or woman is probably more susceptible to pneumonia, tuberculosis, typhoid fever, than is a person whose vital resistance is normal; (*d*) fatigue and nervous diseases—the evidence indicates that long hours of feverish haste among factory workers lead to nervous breakdown; (*e*) fatigue and future generations —the children of overworked parents are likely to be physical weaklings; (*f*) fatigue and morals of working people—long hours of monotonous labor probably increases the susceptibility of the human organism to harmful temptations.

[4] Josephine Goldmark, "The Study of Fatigue," *Survey* (1909), XXII, 534.

The first phase of the general fatigue problem—with which this report is concerned—has not yet been formulated, as far as the writer is aware, as a distinct problem in itself. Investigations relative to accidents have had largely to do with the objective causes; while the more deep-seated and perhaps the more primary causes have been neglected. In spite of the advance which has been made in this country within recent years in the introduction of safety appliances and of a system of factory inspection, an enormous human sacrifice is annually made to production; herein lies the chief reason for this study. A few typical facts are subjoined.

Crystal Eastman found that 526 lives were sacrificed to production in one year, ending June 30, 1907, in Allegheny County, Pa. With respect to accidents, her report says there has been no respite—each year has turned them out as surely as the mills ran full and the railroads prospered. In Allegheny County alone the number would reach 5,000 in ten years—enough to make a small city of cripples.[5]

After carefully investigating the returns from the labor offices of nine states,[6] Gilbert L. Campbell finds that these reports show clearly that in the year 1907, for example, a total of at least 43,713 industrial accidents befell working-men in the states cited, and that 3,436 of these accidents were fatal.[7] In regard to accidents befalling railway employees, Mr. Campbell bases an estimate on the statistics gathered by the Interstate Commerce Commission and states that during the seven-year period, 1902–7 inclusive, 335,974 employees were injured and 23,895 were killed. Of the trainmen alone 218,082 were injured and 14,888 killed.

> In a given year the trainman has one chance in 127 of death, and one in 9 of injury. Seven years in the train service offer him one chance in 18 of death, and if his place is one of average danger present a practical certainty of injury.[8]

Industry may be charged not only with extravagance of killing and

[5] Crystal Eastman, *Work Accidents and the Law* (Charities Pub. Com., 1910), 12.

[6] These nine states are: Minnesota, Iowa, Wisconsin, Illinois, Michigan, Ohio, Pennsylvania, New Jersey, and New York.

[7] Gilbert L. Campbell, *Industrial Accidents and Their Compensation* (Houghton Mifflin Co., 1911), 9, 10.

[8] *Ibid.*, 15.

maiming yearly thousands of workers, but it seems to choose for its victims many persons in the prime of manhood, normally with years of life before them, and with obligations but partly discharged to wives and children.[9]

Approximately 30,000 wage-earners are killed by accidents every year and at least 500,000 more are seriously injured (in the United States).[10] John B. Andrews says that industry "maims more men than war ever did." Professor H. R. Seager states that the United States "shows every year a larger proportion of industrial accidents on its railroads and in its mines and factories than any other civilized land."[11] Moreover, the resultant suffering and denial of opportunity to the wives and children of the daily increasing numbers of the prematurely dead and of the industrially maimed and handicapped for life are beyond computation. Professor Henderson asks: "Who can set a price on mangled limbs, tortures of men caught in cog-wheels and bands, sawed asunder in mills, and the sorrow, anxiety, and despair of their impoverished families?"[12] The enormous blood-tax which industry daily levies upon wage-earners makes necessary new forms of careful investigation of the causes, one of which may be fatigue.

Difficulties arise at the outset of this inquiry. Fatigue is an illusive phenomenon. It varies with different workmen, with different kinds of work, with different days. It also appears that fatigue develops insidiously and often without the knowledge of the worker. Moreover, physiologists and psychologists disagree as to the nature of the fatigue processes.

Another kind of difficulty is common. When three well-known social and economic writers (two Americans, one European) were communicated with, and asked for the references on the strength of which each had published the definite statement that more accidents occur in the last hours of work than in other hours, no one of them could cite such references. One of the frank confessions reads: "For the statement you quote, I imagine now that I did not have at hand the European statistics, and did

[9] *Ibid.*, 21.

[10] J. B. Andrews, "A Clinic for Industrial Diseases," *Survey*, XXV, 269.

[11] H. R. Seager, *Social Insurance* (Macmillan, 1910), 25.

[12] C. R. Henderson, "Wood-Workers and Their Dangers," *World To-Day* (1910), XIX, 972.

not know where to find them; or I would have been more specific in referring to them."

Attempts to collect new data are difficult. Some employers have established a monopoly of knowledge and of social facts—facts concerning which the public should know. One day in August, 1910, the writer explained to the attorney of a company employing hundreds of men that data regarding accident-hours were wanted. When the attorney had assured himself of the bona fide nature of the inquiry and that personal data, such as names, would be held strictly in confidence, he gave the writer access to accident records covering a period of years and giving the exact time of the accidents. A tabulation of the hours when these accidents occurred was scarcely begun when a high official of the company happened to enter the attorney's office. Almost at a glance he unjustifiably read much into the situation and gruffly said: "This is irregular; we can't have it." A courteous explanation that the sole aim was to secure social facts elicited no response from this apparently anti-social individual other than a curt abbreviation of his first remark.

An investigation of the relation of fatigue to industrial accidents raises difficulties which increase on every hand. On one side is a series of physiological and psychological phenomena; on the other, an equally involved series of objective and social factors. At this point the question might easily have been raised as to whether further study would bring definite results. It was from such an attitude that further inquiry was made. A preliminary study of this phase of the general problem of fatigue in industry raises six important groups of questions, which will be considered in as many sections.

(*a*) While considerable research work has been done in connection with a study of fatigue, each of the inquiries has treated the phenomenon more or less independently of its social significance. Although the physiologists and especially the psychologists have contributed extensively to the study of fatigue,[13] the writer has not seen a description of the manner in which and the extent to which fatigue is psychically related to accidents in

[13] For example, the description of the investigations of Kraepelin and of his colaborers in the laboratory at Heidelberg fill several large volumes of the *Psychologische Arbeiten*.

industry. The discussions regarding fatigue generally stop with analyses of subjective processes. They do not deal with fatigue as a social problem or consider it in relation to a special group of social phenomena—such as accidents.[14] Is there not a need, then, for a concise description of what the physiologists and also the psychologists have discovered that may be used in a study of fatigue as a cause of accidents? The question that is raised here calls for the formulation of a law of the development of the fatigue processes which accompany continued work, in so far as they may be related to accidents.

(*b*) In the next place, how does modern industrial labor affect the normal development of fatigue—in what ways is the development of the fatigue process hastened in the case of present-day working people, and why; and what are the observable circumstances under which these processes result in accidents? (*c*) Can the subjective fatigue processes be measured by means of controlled experiments in terms comparable to the observable conditions preceding accidents, and thus be causally related to accidents?

(*d*) The fourth question is: What are the objective correlates of fatigue in terms of actual accidents, or to what extent do statistics of the hours when accidents occur isolate fatigue from the other and more evident causes? (*e*) Has overfatigue attracted attention to itself to the extent that men of the business and legal world have pronounced it a cause of accidents? Specifically, to what extent do investigations of the causes of railway accidents, for example, by the Interstate Commerce Commission, isolate fatigue as a cause of accidents; and have the courts indicted fatigue as a cause of accidents?

(*f*) In the last place, should not all the facts relative to this problem be brought together in a unified whole? The facts derived (1) from a study of the normal development of fatigue, (2) from a study of pathological fatigue under modern industrial conditions, (3) from an experimental study of fatigue under

[14] *The Brief in Defense of the Ten-Hour Law for Women in Illinois* (1909) by Louis D. Brandeis, assisted by Josephine Goldmark, contains an excellent compilation of opinions from European and American sources regarding different social phases of the fatigue problem. The brief has served as a valuable reference work in the preparation of portions of sections II, III, and V of this study.

controlled conditions, (4) from a statistical inquiry into accident-hours, and (5) from a compilation of legal opinion relating to the problem in hand—will be summarized and presented in defense of the proposition that fatigue is a cause of industrial accidents. To the extent that the facts show that fatigue is a causal factor of work-accidents, a modified method of combating their prevalence will be necessary. One general suggestion in this connection will be made. In the next section a description of the development of the fatigue processes which may lead up to and culminate in industrial accidents will be undertaken.

II. RELATED FATIGUE PROCESSES[1]

Mosso was among the first to point out in a scientific way the fatal struggle between the machine-operative, subject to the laws of fatigue and exhaustion, and the machine itself, powerful and indefatigable.[2] He designates fatigue as a chemical process. The earliest experiments relative to fatigue were of a chemical nature.

Normal muscle-tissue has the power of changing the sugar brought to it by the blood into glycogen ($C_6H_2O_6—H_2O=C_6H_{10}O_5$). The muscle stores away the glycogen thus formed and it becomes a constant constituent of a normal muscle. The glycogen which the muscle has stored away while resting is consumed during activity. If the activity is sufficiently prolonged, the glycogen disappears entirely and exhaustion of the muscle is likely to result. It has been shown by verified experiments that if most of the carbohydrate (or glycogen) be removed from the body of an animal, the organism gives the symptoms of "pronounced fatigue."[3] The same result holds true of individual muscles.

Without doubt, during muscle activity there is a constant

[1] This sketch of the fatigue processes is such as appears preliminary to the formulation of a causal law of fatigue underlying industrial accidents. Only the material germane to a clear understanding of the chapters which follow is presented here.

[2] "Le savant professeur (Mosso) nous montre la lutte inévitable fatale, entre la machine puissante, infatigable et aveugle et l'ouvrier chargé de la conduire, de la guider, mais qui lui, organisme vivant, est soumis aux lois de la fatigue et de l'épuisement."—P. Langlois, Introd., trans. of Mosso's *La fatigue intellectuelle* (Paris, 1904), 12.

[3] F. S. Lee, "The Nature of Fatigue," *Pop. Sci. Mon.*, LXXVI, 185, 186.

drain upon the material from which muscle-energy is obtained.[4] There is a growing loss of power to absorb nutriment from the blood, and a continual tearing down without equal building up. After repeated muscle contractions, the processes of katabolism (tearing down) are in excess of those of anabolism (building up); and prolonged muscular activity is accompanied by an *"exhaustion of energy-yielding material."* It should be added that this exhaustion process goes on not only in the groups of muscles which are being visibly used, but also in the groups of muscles in different parts of the body which are held tense and unrelaxed in guiding the groups of visibly working muscles.

Besides, the mentioned structural changes which accompany work[5] occur not only in muscles but in nerve-cells. Physiological evidence indicates that during mental and muscular activity nerve-cells undergo actual structural changes.[6] (*a*) The nucleus of the nerve-cell shows marked decrease in size; it changes from a smooth and round to a jagged, irregular outline; it loses its open, reticulate appearance. (*b*) The protoplasm of the nerve-cell shows a slight shrinkage, and undergoes vacuolation. (*c*) The cell capsule suffers a decrease in the size of its nuclei. These results were obtained from a study of spinal ganglion and brain-cells electrically stimulated and of those in a state of fatigue produced normally. For certain of these nerve-cells, Hodge found that a period which varied from seven to twenty-four hours was necessary before the cells returned to their previous shape and appearance.

Guerrini's experiments corroborated Hodge's results. He examined microscopically the brain-cells of animals fatigued by muscular work. The more the animal had been fatigued

the more profoundly altered the nerve-cells of its cerebral or cerebellar cortex were found to be. These are, briefly, the modifications which fatigue

[4] W. H. Howell, *A Text-book of Physiology* (Saunders Co., 1909), 71.

[5] It is not intended to make a definite distinction here between mental and muscular fatigue. In all forms of hazardous labor the mental and muscular factors are both inextricably involved as parts of one bodily process, but of course in varying degrees.

[6] See D. F. Hodge, "A Microscopical Study of Changes Due to Functional Activity in Nerve Cells," *Jour. of Morphol.*, VII, 95–168; also "Some Effects of Electrically Stimulating Ganglion Cells," *Amer. Jour. of Psych.*, II, 376–402; also A. G. Levy, "Fatigue of the Cerebral Motor Cortex," *Brit. Med. Jour.* (1900), 741.

produces on the microscopic structure of the nerve-cell, and more evidently in that of the cerebral than in that of the cerebellar cortex, and most of all in the structure of those nerve-cells which correspond to the motor zones.[7]

This progressively exhaustive chemical process has another significant phase for this paper. As a result of his experiments, Ranke came to the belief that certain substances which inhibited the power of muscular contraction were formed as a result of the chemical processes occurring during contraction. He named these, "fatigue substances" ("ermüdenden Stoffe").[8]

In the extracts of normal muscle, parcolactic acid ($C_3H_6O_3$) is found but slightly, while the amount greatly increases during muscle activity. Mosso calls attention to the fact that before the close of the 18th century Lavoisier and Sequin, by a series of memorable chemical analyses, demonstrated that muscular work increased the amount of carbonic acid eliminated from the system. A laborer expires nearly twice as much carbon dioxid during a working day as during a resting day. The carbon dioxid results from the oxidation of the carbon found in the constituents of the muscle. Monopotassium phosphate (KH_2PO_4) is another of the important and definitely determined fatigue substances.[9] These substances seemed to be formed also in the nerve-cell during activity.[10]

In the next place, the fatigue substances mentioned exert *a poisonous and paralyzing effect* upon the whole organism. Both parcolactic acid and carbon dioxid "when in any but small quantity are inimical to protoplasmic activity, and furthermore, ... a muscle under their influence shows the very same physical symptoms that are shown by a muscle fatigued through work." After investigating a large amount of testimony from physicians and physiologists, both European and American, Brandeis and Goldmark state:

They [the unexpelled products of fatigue] circulate in the blood, poisoning brain and nervous system, muscles, glands, and other organs until normally removed by the oxygen of the blood, by the liver or kidneys. . . . . When they exceed their physiological or normal amount, exhaustion results. . . . .

[7] Guido Guerrini, "Preliminary Account of the Influence of Fatigue on the Structure of the Nerve-Cells," *Lancet*, II, 1087.

[8] J. Ranke, *Tetanus* (Leipzig, 1865), chap. xv, "Die einzelnen ermüdenden Stoffe."

[9] Howell, *op. cit.*, 70.

[10] *Ibid.*, 139.

In extreme instances of overexertion death results, not from sheer exhaustion of the heart, but from chemical poisoning due to the unexpelled products of fatigue.[11]

In this connection, Dr. H. B. Favill says:

Any living organism will die promptly if the waste products (including the fatigue substances) from its life processes accumulate. . . . . Laboratory research, verified by many competent observers, indicates that there are created in the process of muscular work . . . . *substances of a nature distinctly poisonous.*[12]

Besides the fatigue substances mentioned, Weichardt states that muscular contraction produces a definite toxin (kenotoxin).[13] He found kenotoxin in the muscle juices ("Muskelpreszsaft"); and in addition to the known fatigue substances. When injected into an animal, kenotoxin produces fatigue; in large doses it causes death ("wirkte er ermüdend und in groszen Doses, tödtlich"). Weichardt has definitely isolated both kenotoxin and its antitoxin ("beide Substanzen, habe ich isoliert dargestellt und zu ausgedehnten Versuchsreihen verwendet"). These results have been verified by Dr. Wolff-Eisner.[14] They add weight to the fact that the known fatigue substances possess a toxic and paralyzing nature.

It appears that the fatigue poisons accumulate first, not in the muscles actually moving but in the groups of tense, nonmoving muscles, which are used in guiding the given activity. These muscles are poorly irrigated. But sooner or later the fatigue substances accumulate in the moving muscles, even though these are better irrigated. The toxins also circulate in the blood throughout the body. Howell describes the twofold chemical process accompanying work as (*a*) an exhaustion of energy-yielding material, and (*b*) an accumulation of the products of katabolism (the fatigue substances).[15] Verworn refers to the

[11] L. D. Brandeis (assisted by Josephine Goldmark), *Brief in Defense of the Ten-Hour Law for Women* (Ill., 1909), 77, 78.

[12] H. B. Favill, "The Toxin of Fatigue," *Survey*, XXIV, 769.

[13] See W. Weichardt, "Ueber das Ermüdungstoxin und Antitoxin," *Münch. med. Wochenschr.*, LI, 2122–26, LII, 1234–36; "Ermüdungs- und Ueberermüdungsmaszmethoden," *Deutsche Vierteljahrschr. f. öffentl. Gesundheitspfl.*, XXXIX, 324–34.

[14] See A. Wolff-Eisner, "Ueber Ermüdungs- und Reduktionstoxine," *Centralbl. f. Bakteriol.*, 1 Abt., XL, 634–44.

[15] Howell, *op. cit.*, 71.

using up of energy-yielding material as culminating in "Erschöpfung"—a literal exhaustion; and to the production of fatigue substances as resulting in a state of "Ermüdung."[16] The change that takes place in the reaction of an active muscle, in the size of an active nerve-cell, and in the amount of waste material thrown off by the organism when it becomes active, leaves little room to doubt that there is a direct relation between structural changes and activity.

This conclusion brings up the related functional changes accompanying work. For the purpose of this study, the fatigue process may be treated as centering around the objective phenomenon of *increasing muscular inaccuracy*. Because of the using up of muscle material and because of the accumulation in the muscles of the fatigue-toxins, a given group of working muscles gradually *become less able to respond* to the demands made upon them by the psychical-neural apparatus. If rapidly repeated stimuli of equal strengths at equal intervals be applied to a muscle, it is found that at first the contractions increase in extent (forming the "treppe"), that after a certain period the contractions begin to diminish steadily in height until finally the muscle will fail to respond to the stimulus. This progressive loss of irritability in the muscle, caused by repeated activity, has been designated as fatigue.[17]

Ergograph experiments (where the stimulation of the muscle is not artificial, but voluntary) show that after a state of complete fatigue has been reached with a given task, a very long interval is necessary for the muscle to make complete recovery.[18] Mosso lays stress on the fact that Professor Maggiora proved that two hours' rest is necessary before the fatigue traces are completely removed from the flexor muscles of the fingers after they have been exhausted by a series of contractions in the ergograph.[19]

Maggiora found that the last smaller contractions of muscles are more exhaustive than the first large contractions.[20] After

[16] Max Verworn, *Allgemeine Physiologie* (Jena, 1909), 557.

[17] Howell, *op. cit.*, 34, 35.

[18] *Ibid.*, 49. The ergograph is a special instrument devised by Mosso, by means of which the muscle is given a specific work to do, such as lifting a weight.

[19] A. Mosso, *Fatigue* (Paris, 1904), trans. by the Drummonds, 150.

[20] A. Maggiora, "Ueber die Gesetze der Ermüdung," *Arch. f. Anat. u. Physiol.* (1890), 213.

muscles are completely fatigued, still further efforts to contract them greatly prolong the period of complete recovery. Work which calls for contractions of tired muscles is much more injurious ("viel schädlicher") than greater muscular tasks under normal conditions.[21] Verworn states that a fatigued muscle requires a considerably longer time ("unvergleichlich mehr Zeit") for relaxation than does a normal muscle.[22] It is the long interval of recovery, a period unduly long for the removal of the katabolic products due to the activity of a single muscle, which leads to the belief already cited that fatigue is partly due to consumption of muscle-material itself, which has to be replaced by anabolic or building-up processes before the muscle is entirely free from fatigue effects.[23]

Other things being equal, the rate at which the working muscle becomes less responsive to stimulation depends (*a*) upon the *rapidity* and (*b*) upon the *difficulty* of the given piece of work. Kronecker found that the more rapid is the rhythm in which muscular contractions are produced, the more rapidly does the height of these contractions diminish; and vice versa.[24] By using the ergograph, Winfield S. Hall found that if a muscle be given a load proportional to the actual strength of the muscle and if the muscle be allowed to rest from the strain of the weight during the period of relaxation, the time of the fatiguing process may be indefinitely prolonged.[25]

Not only do working muscles become less able to respond to stimulation because of fatigue, but they *receive less and less efficient stimulation* from the psychical-neural apparatus. It appears that with the exhaustion of energy-giving material and with the accumulation of the toxic fatigue substances in the parts used and in those portions of the muscles located at any place in the body that are under tension in guiding the activity of the muscles that are working, *inhibitory impulses* ascend along the afferent fibers, with which every muscle and tendon is supplied, to

[21] *Ibid.*, 211.

[22] Max Verworn, *op. cit.*, 548.

[23] W. H. Howell, *op. cit.*, 71.

[24] See C. S. Yoakum, *An Experimental Study of Fatigue* (The University of Chicago Press, 1909), 3.

[25] W. S. Hall, *Bulletin* (Northwestern Medical School, Chicago).

the motor centers of the cortex and cord. Myers says that the afferent fibers running from the muscular (and other) tissues of the body to terminate around the cells of the motor nuclei of the cord, bulb, and mid-brain, play an important part in reflexly co-ordinating muscular action.[26] The various motor centers of the cord which control the movements of flexion and extension are alternately excited or inhibited, owing to the play upon them of afferent impulses peripherally derived from the movements themselves. Whatever disturbs these afferent impulses disturbs muscular co-ordinations. The using up of muscle material and the accumulation of fatigue substances appear to increase the inhibitory action of afferent impulses.

The neural apparatus also becomes less efficient in guiding the working muscles because of the structural changes going on in the nerve-cells. Dearborn says that nerve-cells do become exhausted progressively, however slowly, even in cases where their blood-supply is ample and their vigor normal.[27] Tigerstedt says that by a method especially adapted to the purpose it may be shown that the nervous mechanism is being greatly strained before there is any sign of fatigue in the external work done.[28] In summing up the situation regarding nerve-cell fatigue, it may be said that it seems probable that under normal conditions some portions of the nerve centers remain in more or less constant activity during the day without showing a marked degree of fatigue, just as muscles remain in a more or less continuous state of contraction throughout the waking period.[29] But when the nerve centers are strongly stimulated the fatigue is more marked "because the processes of repair in the nerve centers cannot then keep pace with the processes of consumption of materials."[30]

Another factor which affects the efficiency of the neural apparatus in guiding the active muscles, has been mentioned, namely, the poisoning and paralyzing effect of the fatigue substances

[26] C. S. Myers, *Experimental Psychology* (Longmans, Green & Co., 1909), 186.

[27] G. V. N. Dearborn, "On the Fatigue of the Nerve Centers," *Psych. Rev.*, IX, 182; see also W. H. Burnham, "The Problem of Fatigue," *Amer. Jour. of Psych.*, XIX, 385.

[28] R. Tigerstedt, *A Text-book of Human Physiology* (Appleton, 1906), trans. by Murlin, 446.

[29] Howell, *op. cit.*, 138. [30] *Ibid.*

which circulate through the brain and other centers of control. The structural and functional fatigue changes which have been described may be briefly summarized at this point. Not only do muscles become less responsive to stimulation (because of the using up of energy-giving material and because of the paralyzing effects upon them of the fatigue substances), but the muscles receive less and less efficient stimulation from the neural apparatus (because of the effects upon the neural apparatus by the inhibitory impulses from both the tense and the moving muscles, by the structural changes in the spinal ganglion and central nerve-cells, and by the poisonous fatigue substances circulating through the higher neural centers).

The combined effects of these forces result in *increasing muscular inaccuracy*. Muscular co-ordinations become seriously hampered and irregular. The loss of control over the muscular co-ordinations consists first in "the immeasurably short shifts and 'blockings' of the more finely adjusted musculature . . . . on to the grossest muscular contractions that finally cease to respond to the effort of the will."[31]

Loss of muscle control as indicated by the progress from blocking of the more finely adjusted musculature on to failure to make the grossest muscular contractions is not adequately represented by a continuous descending slant. Increasing fatigue when brought to the notice of the worker leads to temporary spurts, that is to say, to an increase in the volitional strain or attention which he brings to bear on his task. Although the fatigue process may go on for a time unnoticed, it sooner or later appears in consciousness in the form of "sensations." These sensations may arise first as feelings of effort, then as feelings of strain, then as sensations of fatigue.[32] The fatigue sensations are warnings. They indicate that the organism demands "a shift in the working mechanism." By tremendous effort, a fatigued worker may for a short time bring to his labor a striking degree of volitional attention.

These spurts appear irregularly, and there are alternating and irregular periods of depression or bad spells when the worker

[31] Yoakum, *op. cit.*, 114. [32] *Ibid.*, 117.

is less able to give attention and when the co-ordinations are less likely to be correct than during the periods of volitional strain. Beyond doubt, the periods of depression are due to flagging interest and increasing fatigue.[33] Hence, during uninterrupted work and as soon as fatigue effects predominate over skill due to practice, there sets in an irregularly decreasing control over muscle co-ordinations. The time at which fatigue is likely to overcome practice during a given period of work depends among other things upon the rate and difficulty of the work, as already noted, for the given individual. At the beginning of a period of uninterrupted work there is likely to be uncertain muscle control, due to the necessity of getting "warmed up" and occasionally to nervous excitement attendant upon beginning a piece of work. Then for a certain length of time the muscle control is likely to be good—due to practice effects.[34] When practice gain is overcome by fatigue effects, then muscular inaccuracy becomes a developing and important factor. During this period effort is expended in waves of force that approximate what Treves calls the irregular progress of mental fatigue rather than the regular decline of muscle power.[35]

Muscular inaccuracies may be of two kinds: one may keep up with the rhythm of work and make spatial maladjustments; or one may make accurate spatial movements, and fall behind the rhythm; or one may do both. Thus muscular inaccuracies may be not only of a *spatial* nature, but may involve a *time* element as well. Mosso says:

> The time of physiological reaction . . . . is the name given to the interval between the occurrence of an electric spark, for instance, and our giving some sign of having perceived it, say by touching an electric button on which our hand rests. This short space of time . . . . represents the delay which takes place before we take account of one of the most simple forms of perception. . . . . *Fatigue has great influence on the duration of this reaction time.* When such measurements are repeated without an interval for rest, the time before the response is given gradually increases.[36]

[33] Myers, *op. cit.*, 194.

[34] A. Binet, *La fatigue intellectuelle* (Paris, 1898), 334; also E. Kraepelin, *Philos. Studien*, XIX, 459–507.

[35] Yoakum, *op. cit.*, 42.

[36] Mosso, *op. cit.*, 205.

A delay in promptness of reaction[37] and a greater number of faults of memory and attention are noticeable after fatigue.[38] It is almost impossible to be attentive when the brain, for instance, is fatigued.[39] The length of time that ordinarily elapses before one responds with the hand, for example, to a touch on the foot may be doubled as a result of the effects of fatigue on attention.[40]

The effect of fatigue on attention—which is such an important factor in failure to make accurate muscular co-ordinations—appears to have its basis in the difficulty of maintaining the tensions which are guiding the given activity. It is not possible to maintain one set of tensions long without physiological changes taking place. And any physiological changes may while they are still subconscious be the "cue" for a change of attention to some other topic of thought, a change which may involve a new set of tensions—and thus the process continues. Or, the physiological changes referred to may come to consciousness in the form of sensations of fatigue, and in this case there is a change of attention to the point of origin or to the sensations themselves, and vigilance over muscular movements is temporarily suspended.

In the case of monotonous division of labor where the workman must attend continually to one single uninteresting point or part of a machine the same neural-muscular apparatus must be used, the same tensions must be maintained. The difficulty of maintaining this situation with little if any variation becomes increasingly great. If the task in hand requires constant attention, increasing muscular inaccuracy is likely to result—immediately due to the effects of fatigue on attention. The degree of muscular inaccuracy is determined partly by the inability of muscles to respond—according to their state of wear and tear and to the amount of fatigue substances which have accumulated—and partly by the inability of the neural apparatus to attend to

[37] "Reaction time includes such phenomena as (*a*) the latent period in the sense organ, (*b*) time of transmission along the afferent nerve, (*c*) resultant processes within the central nervous system, (*d*) time of transmission along the efferent nerve, and (*e*) the latent period in the muscle."—J. M. Cattell, "The Time Taken by Cerebral Operations," *Mind*, XI, 230.

[38] Z. Treves, "Dans quelle mesure peut-on, par des méthodes physiologiques, étudier la fatigue," etc., *13 Cong. Intern. d'Hyg. et Demog.*, V, sec. 4, ques. 3, p. 37.

[39] Mosso, *op. cit.*, 198.

[40] *Ibid.*, 205.

the movements of the given muscles—according to the number of and the state of the tensions which can be relied upon in guiding the given activity.[41]

Muscular inaccuracy is increased especially where the regular effects of fatigue on attention are augmented by a general condition of overfatigue of the whole system, that is to say, by a state of chronic overfatigue. Pathological fatigue also results in "increasing inaccuracy of judgment,"[42] which in turn increases muscular inaccuracy. Overwork blunts all the psychic activities and diminishes sensibility; and hence *diminishes the precision of movements and the exactness of the rhythm.*[43]

It has been pointed out in this section that uninterrupted muscular work results in using up of energy-yielding material of muscles and of nerve-cells, and in the accumulation of toxic waste substances, with an accompanying decrease in muscle irritability and activity, and inability of the neural apparatus to attend to muscle movements, i.e., with a corresponding and increasing irregularity in the co-ordination of muscular action. The rate at which these various phases of the fatigue process takes place is dependent on the rate and difficulty—including monotony—of the given task.

If stated in terms of the subjective conditions which the writer believes quite generally precede accidents, a summary of this chapter may be given psychological expression. The resultant and germane law of fatigue is: *Uninterrupted muscular activity is accompanied by inaccurate muscular co-ordinations, which increase irregularly and at a rate largely determined by the speed and relative difficulty of the activity for the given individual.*

[41] See Yoakum, *op. cit.*, 99–124; also Myers, *op. cit.*, 186 ff.

[42] E. W. Scripture, "Researches in Reaction Time," *Yale Studies*, IV, 12–16, 69–75.

[43] J. de Moor, *13. Intern. Kong. f. Hyg. u. Demog.*, Pt. I, 5, sec. 4, ques. 3, p. 9.

[*To be continued*]